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NAVY EXPERIMENTAL DIVING UNIT
PANAMA CITY, FLORIDA 32407-5001

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NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 09-91

# COMPARISON EVALUATION OF EXPLOSIVE DIVER RECALL DEVICES

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MARCH 1991



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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The Navy Experimental Diving Unit evaluated non-developmental explosive diver recall devices for inclusion on the Diving Equipment Authorized for Navy Use List. The devices tested were: Broco MK 2 MOD 0 and MOD 1, Hands Fireworks SC-81 and SC-810, Compact Energy, Ltd. N1 MK 1, and the military M-80. Characteristics that were evaluated include acoustic output, fragmentation production, human factors, operational reliability and end item cost. Based on the comparison of these factors, the Broco MK 2 MOD 0 is deemed most suitable for Navy SCUBA operations where an explosive type recall device is required. Also, due to safety and reliability problems, it is recommended that the M-80 (NSN 1370-00-028-5252 be removed from the ANU as soon as suitable substitutes are in the fleet.

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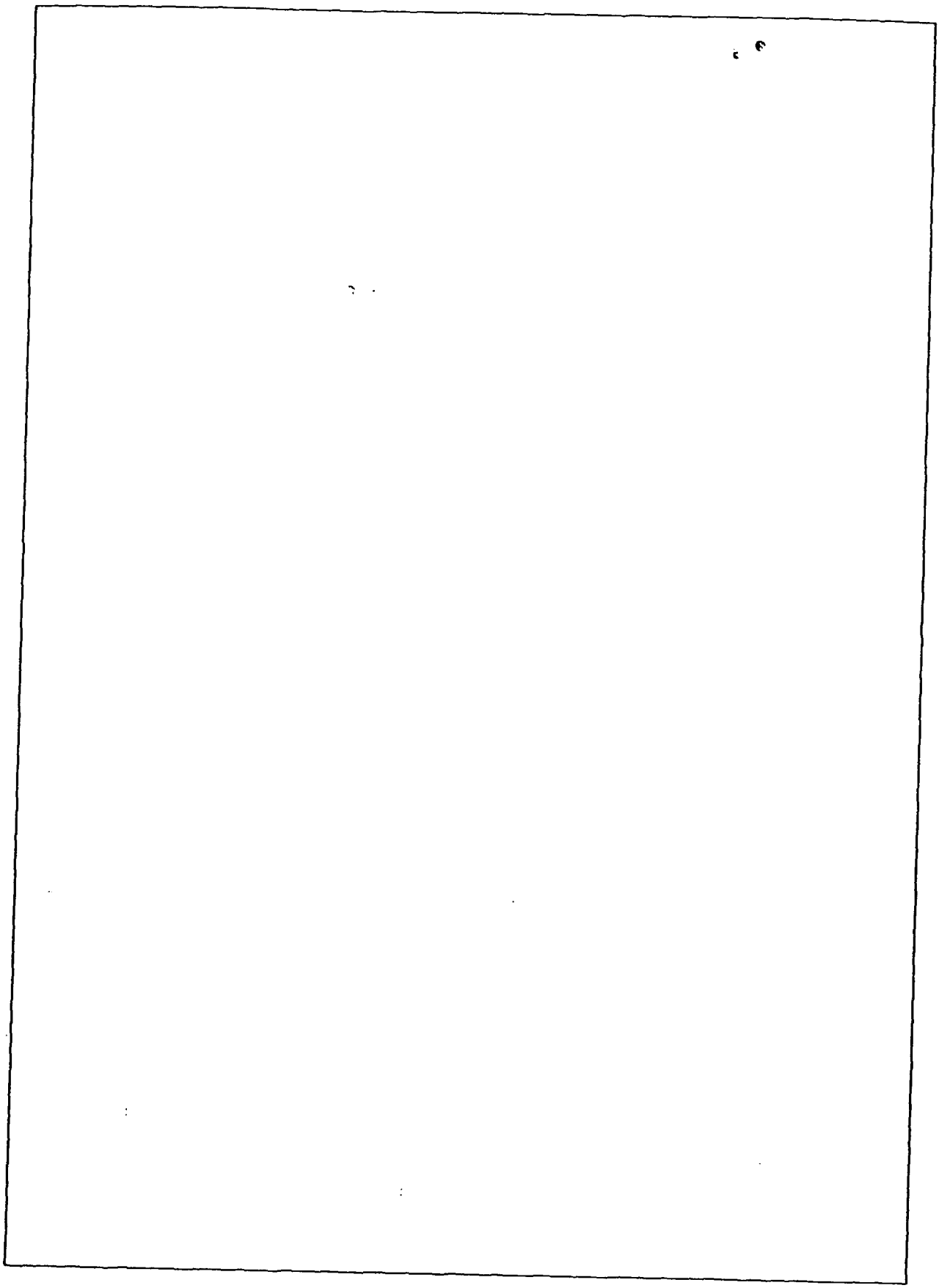

## GLOSSARY

| | |
|---|---|
| ARD | Audible Recall Device |
| c | velocity of sound |
| dB | decibel |
| msec | millisecond |
| NAVSEA | Naval Sea Systems Command |
| NCSC | Naval Coastal Systems Center |
| NEDU | Navy Experimental Diving Unit |
| p | density of water |
| Pm | measured sound pressure |
| $P_{ref}$ | referenced sound pressure |
| psi | pounds per square inch |
| (re 20 uPa) | sound pressure has been referenced to 20 uPa |
| sec | second |
| SPL | sound pressure level |
| $SPL_{air}$ | sound pressure level measured in air |
| $SPL_{water}$ | sound pressure level measured in water |
| uPa | micro pascals |
| Z | impedence of water |

## CONTENTS

## ILLUSTRATIONS

## I. INTRODUCTION

Navy Experimental Diving Unit (NEDU) was tasked by reference 1 to conduct an international market survey of non-developmental explosive diver recall devices, procure samples and test these devices regarding suitability for use by U.S. Navy divers. NEDU has evaluated other explosive recall devices per references 2 and 3. The modified audible recall device (ARD) was recommended for use and subsequently added to reference 4. Since that time, the price and availability of that device has made daily use cost prohibitive, necessitating this search for an alternate explosive recall system.

Market research identified five off-the-shelf devices that could potentially meet all identified requirements. These include the SC-81 and SC-810 diver recall devices produced by Hands Fireworks, Inc., Ontario, Canada, the N1 MK 1 diver recall signal from Compact Energy, Ltd., Worcestershire, England, and the MK 2 and MK 2 MOD 1 swimmer recall devices manufactured in the United States by Broco, Inc., Rialto, California. In addition, the detonation simulator M-80, NSN 1370-00-028-5252, was tested (Figure 1). The M-80 is listed in reference 4 and has been used by divers for several years, but little documentation is available concerning potential hazards to divers from this device.

Other factors evaluated include the amount of fragmentation produced, operational reliability, human factors, and end item cost for each device. Additionally, the distance from a free swimming diver that these devices can be reliably heard was determined.

## II. FUNCTIONAL DESCRIPTION

### A. BROCO SWIMMER RECALL DEVICE MK 2 MOD 0/MOD 1 (FIGURE 2)

These devices are functionally the same, the only difference being the net explosive load, therefore both will be described.

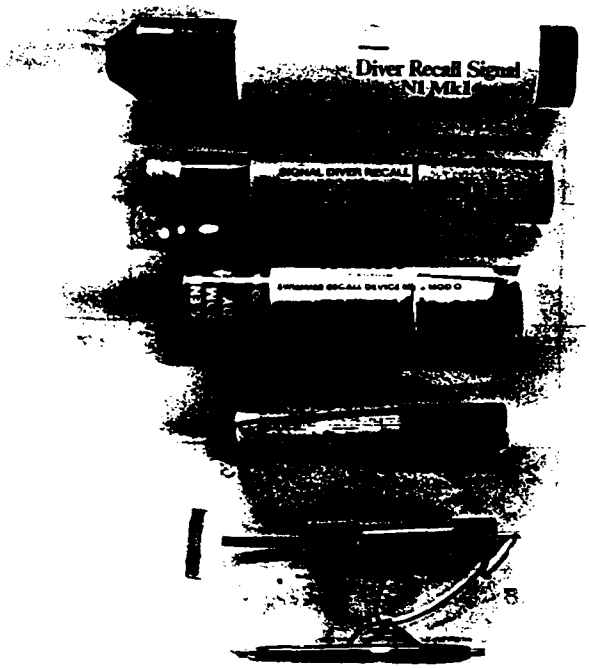


Figure 1. All Recalls Tested

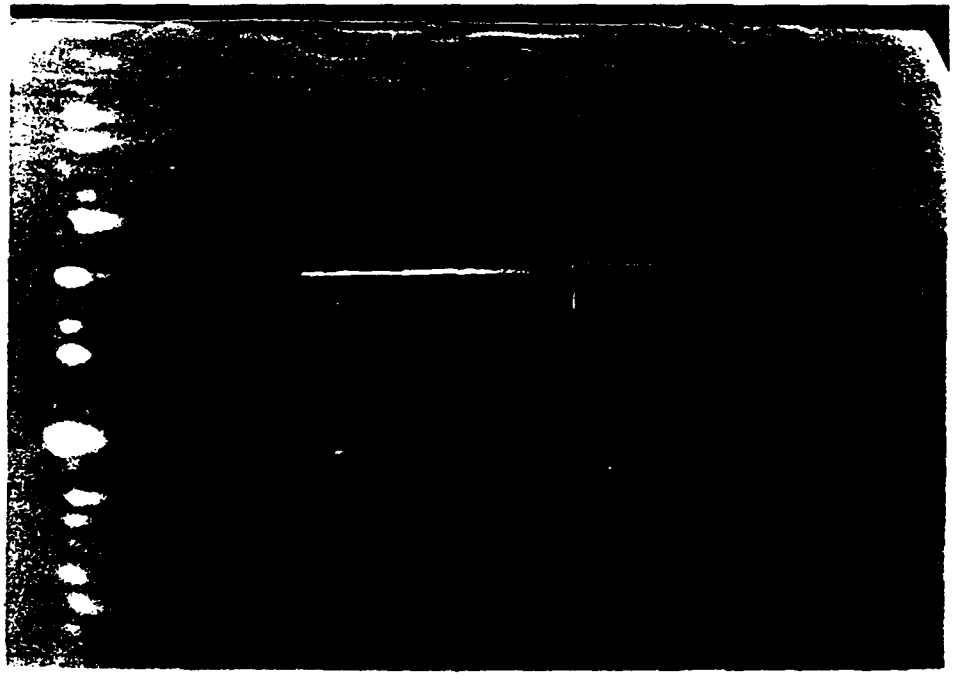

Figure 2. Broco MK 2 MOD 0

These devices are tubular, 222 mm (8.875 inches) long by 32.5 mm (1.3 inches) in diameter. One end, colored red, is to identify the location of the explosive charge. The remainder of the tubular device contains a quick strike match, delay fuse, and a mixture of sand and shot to provide sufficient weight to make the device sink to the desired depth before it detonates.

Procedure for Use:

1. Remove the safety wire by pressing firmly against its looped end until the circular spring clip is disengaged from the body of the tube.

2. Slide the safety wire out of the holes in the yellow end cap.

3. Carefully remove the yellow end cap and allow the cord and pull-ring to fall free from the tube end.

4. Grasp the Swimmer Recall Device firmly in one hand, making sure that fingers are kept well behind the RED AREA.

5. Grasp the Swimmer Recall firmly in the throwing hand. With the other hand, pull the ring sharply to ignite the fuse. Immediately throw the device into the water. The device functions after a 6-second delay.

## B. HANS FIREWORK'S SC-81 DIVER RECALL SIGNAL (FIGURE 3)

This device consists of an outer cardboard shell that houses the internal explosive charge, mounting components, external fuse and friction igniting compound. The unit measures 114.3 mm (4.5 inches) long x 25.4 mm (1 inch) diameter. The protective/striker cover slides over the main body shell and is cushioned from the igniting compound by a cotton patch. Each device comes individually wrapped in a plastic environmental protective bag. To utilize the device, it is removed from the protective bag, then the protective cap and cotton is removed. To light, the abrasive compound on the striker cap is slid against the ignition compound atop the main body.

Figure 3. Hans Fireworks SC-81

This compound lights the external fuse which burns down the outside of the device providing a 6-7 second delay.

## C. HANS FIREWORK'S SC-810 SIGNAL DIVER RECALL (FIGURE 4)

This device consists of a cardboard cylinder 212.7 mm (8.375 inches) long by 31.75 mm (1.25 inches) diameter. The main body houses the main charge, weighting material and fuse. The rigid delay fuse protrudes approximately 254 mm (1 inch) from the diameter center at one end of the device. In storage, this fuse is covered by striker cap held in place by tape. The units come packed in an environmentally sealed bag containing ten devices.

To utilize the device it is first removed from its environmental protection bag. Then the tape is removed from the striker cap exposing a red phosphorous striker band. The delay fuse with integral match-head surface is exposed by removing the striker cap. To ignite, rub the striker band firmly on the match-head. These units are designed with a sink rate of 2.5 foot/second and a 6 second delay.

## D. COMPACT ENERGY LTD. DIVER RECALL SIGNAL N1 MK 1 (FIGURE 5)

This device consists of a rigid plastic body measuring 270 mm (10.62 inches) long by 42 mm (1.65 inch) diameter with a threaded securing cap at one end. All other components are internal and include a movable piston, firing spring, striker, and primer main charge. They come packed in a ".50 cal" size, environmentally protected ammunition box containing nine devices.

To use the device, the securing cap is unscrewed and discarded. The signal is dropped into the water and functions upon reaching its operating depth. As it sinks, water pressure acts on the internal piston, forcing it forward and increasing pressure on the firing spring. The striker is kept in position by steel balls held in the striker recess groove. When the piston has travelled forward approximately 15 mm (.6 inch), the steel balls are able to move out into the piston recess groove. This allows the striker to move forward under spring tension and hit the primer which fires and initiates the main charge. The average detonation depth occurred at 9.22 m (30.24 feet).

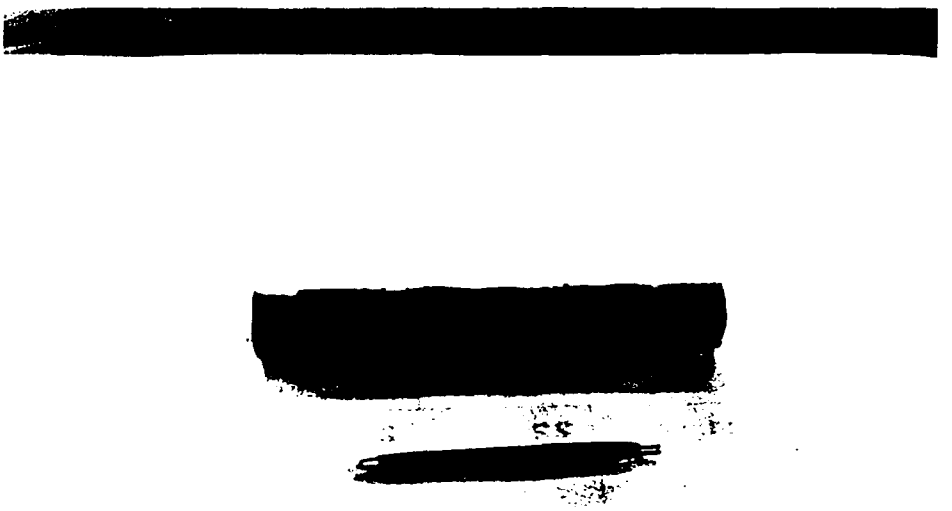

Figure 4. Hans Fireworks SC-810

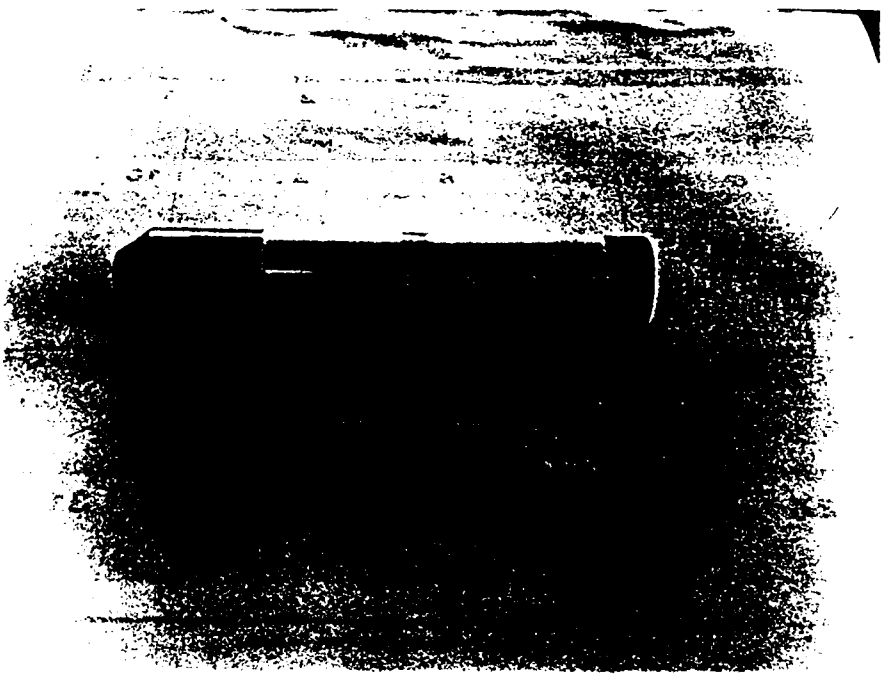

Figure 5. Compact Energy Ltd. N1 MK1

## E. U.S. ARMY DETONATION SIMULATOR M-80 (FIGURE 6)

The M-80 is a U.S. military device identified by NSN 1370-00-028-5252, NALC L378 and is approved for Navy use as a diver recall device in reference 4. Reference 5 lists the N.E.W. of this device as 2.99 grams of explosive.

Preliminary testing showed that these devices, as shipped, will float when thrown in the water, thus producing a fragmentation hazard as well as an inadequate diver recall device. To overcome this problem, a small weight was attached to each device. While solving the sink problem, this led to another difficulty. It was demonstrated in ten of ten attempts, the integral fuse would extinguish in approximately 2 FSW. Several attempts at alternative initiating systems led to the incorporation of an igniter, time blasting fuse, M-60 (NSN 1375-00-283-9452, NALC M766) and 50 mm (2 inches) of fuse, time blasting M700 (NSN 1375-00-028-5151, NALC M670). This combination produced a safe, reliable initiation system which ensured the modified device sank to the desired detonation depth without attachment of additional weight. However, it was necessary to seal the time fuse into the M-80 with Dow Corning "RTV" to prevent absorption of water into the explosive.

To utilize the device, the M-60 fuse lighter was fired by removing the safety pin and sharply pulling on the pull ring. This releases the firing pin, initiating the primer which lights the M700 time fuse. The use of 50 mm (2 inches) of fuse led to a delay of approximately 7 seconds which produced a detonation depth of approximately 3.65 m (12 feet).

# III. METHODS

## A. BACKGROUND

The methods used during this evaluation were duplicates of those used in the evaluation of the audible recall device (ARD), NSN 1370-01-251-5792, NALC 3W92, reference 3. This allowed for direct comparison to the the original ARD evaluation results.

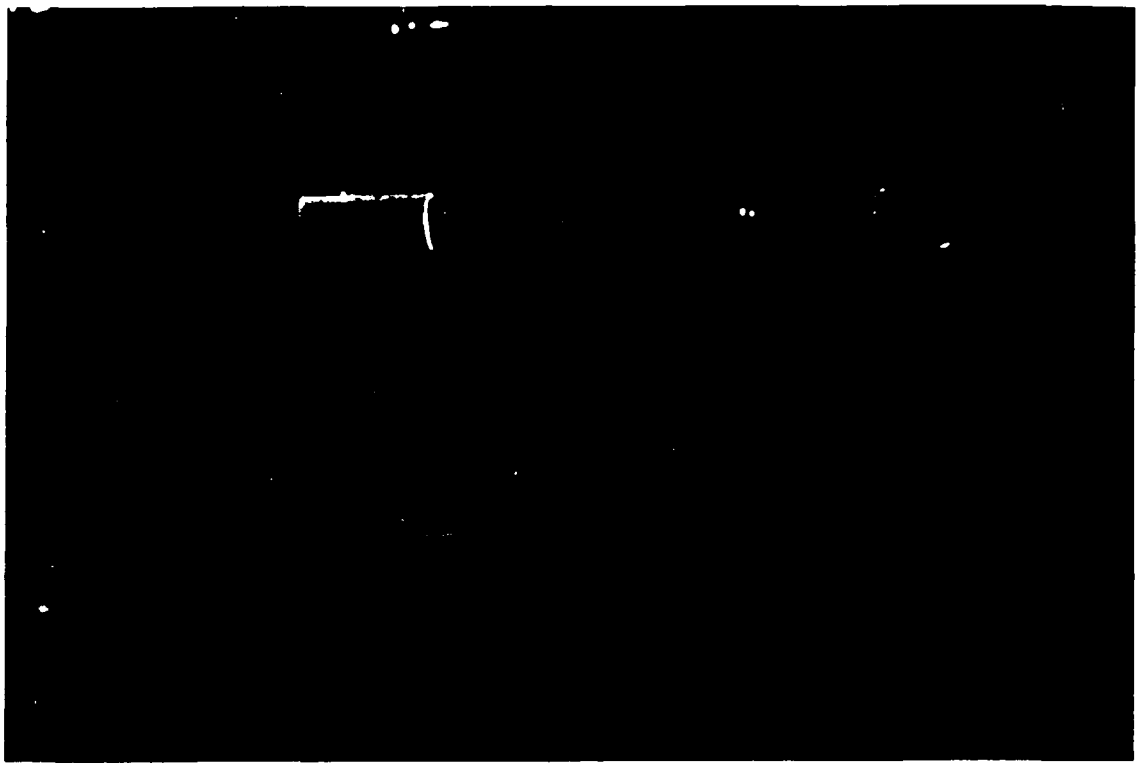

Figure 6. Military M-80

The criteria for safety of an unprotected swimmer exposed to underwater blasts takes into account several factors: sound pressure level (SPL), duration of the positive impulse wave, and impulse sound frequency. As documented by reference 6, divers exposed to 186.4 dB of sound experienced no auditory damage even though this was 11.4 dB above the safe exposure limit of 175 dB (in water) established by reference 7 and calculated as in reference 3. This study establishes the device's minimum standoff distance from a diver ensuring the safe exposure limit of 186.2 dB and 2.17 psi x msec derived from reference 3 is not exceeded.

## B. ACOUSTIC MEASUREMENTS

The Naval Coastal Systems Center (NCSC) in Panama City, Florida provided use of the Acoustic Test Facility for unmanned testing of the diver recall devices. The Acoustic Test Facility is a 6.1 m (20 feet) deep fresh water pond at 23.8°C (75°F) water temperature with a centrally placed pool liner allowing both filtration and chlorination of the acoustic test pool area. The gantry and walkways were structurally outside the pool area reducing noise artifact. During testing of these devices, one wide band tourmaline gauge hydrophone was used to record the impulse on a magnetic floppy disk.

All devices were exploded at a depth of 3.69 m (11 feet) to avoid the acoustic thermocline at approximately 3 m (9.8 feet). Hydrophones were maintained at a constant depth of 3.69 m (11 feet). To obtain a 20 m (65 feet) distance between the test hydrophone and the exploding devices, the devices were fired outside the pool liner in the pond water with the hydrophone inside the pool liner. Earlier tests verified that the liner did not alter the SPL or the frequency spectral analysis of the tests. Furthermore, orientation of the devices underwater did not influence peak sound pressure level (SPL).

## C. MEASUREMENT OF SOUND UNDERWATER

The Explosive Sound Generated (SPL) is measured with the SPL measured in decibels (dB). SPL is actually a logarithmic ratio of the measured sound pressure (Pm) divided by a reference sound pressure (Pref). OPNAVINST 5100.23B (reference 7) defines hazardous noise as sound pressure in air which exceeds 140 dB.

Acoustic impedance difference and in water, in air conversions were calculated from equations derived in references 2 and 3.

The criteria for safety of an unprotected swimmer takes into account SPL is psi, duration in milliseconds (MSEC), and frequency range. Guidelines state the exposure to impulse noise must be less than or equal to 2 psi. MSEC and peak over-pressure must be less than or equal to a SPL of 100 psi (references 8 and 9). It is also believed that an unprotected swimmer could possibly tolerate up to 10 psi MSEC, but research has demonstrated minor small blood vessel damage to lungs and gastrointestinal tract. As reported, these injuries were not considered life threatening and were determined to be acceptable minor injuries under some operational conditions (reference 8). Recent studies at NEDU demonstrated that divers could be exposed to SPL of 186.2, equivalent to 5.85 psi, with a duration of 1 MSEC which calculated to 2.173 psi-MSEC without acoustic injury.

## D. FRAGMENTATION STUDIES

### 1. Air Detonation Tests

Since it is a possibility that these devices, with the exception of the N1 MK1, could inadvertently detonate aboard a diver support platform, a study to determine the fragmentation hazard above water was undertaken. A metal frame was constructed to hold the devices in a vertical position 2 feet from the ground. A circular perimeter of plastic (Visqueen, 0.006 inches thick) was constructed to absorb fragmentation particles. This perimeter started at a distance of 1 foot from the device and was moved outward in 1 foot increments. Figure 7 shows the standard orientation for the test equipment.

### 2. In-Water Detonation Tests

As these devices are designed to detonate underwater, a determination of the fragmentation hazard to a diver was conducted. It was intended to duplicate the dry land testing procedures until no fragmentation was recorded on the witness sheet. This

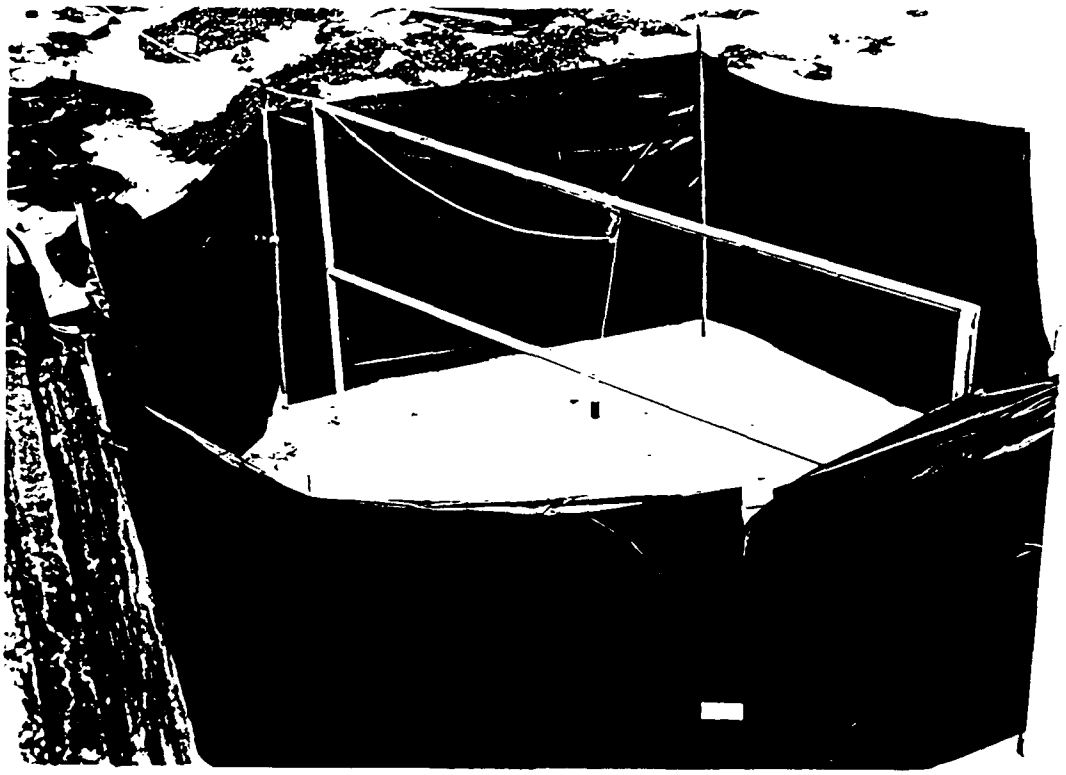

Figure 7. Fragmentation Study Zone

was done at a 1 foot depth underwater to simulate a worse case situation in the lowest density of water.

## E. SIGNAL RELIABILITY

This study was designed to determine the maximum distance from each device at which divers would unmistakably discern the recall signal. This test was conducted in 18.28 m (60 feet) of saltwater. The area for this study had a hard sand bottom, free of reflective obstructions. Divers were stationed on the bottom starting at 91.44 m (100 yards) from the point of detonation. Each device was fired and a report from the divers concerning the extent of audibility was recorded. This procedure was then repeated at 182 m (200 yards), 274 m (300 yards), 365 m (400 yards) and 457 m (500 yards). A device which could be unmistakably heard at 457 m (500 yards) is adequate for U.S. Navy SCUBA diving operations.

## F. HUMAN FACTORS

During this study, in excess of 22 different diving supervisors fired each device at least once. After firing each device, they were required to complete a Human Factors Questionnaire (Annex A). They were encouraged to document all opinions and observations.

## G. DEVICE COST

This comparison will serve to give a relative example of the cost of each device. The figures given should be used only for comparison since production costs may influence future figures.

# IV. RESULTS

## A. UNMANNED ACOUSTIC TESTING

Table 1

Distance for Each Device to Produce 186.2 dB (re 20 uPa)and <2.17 psi/msec

| Device | Distance | N = Number of Tests This Device |
|---|---|---|
| Broco MK 2 MOD 0 | 10.99 m (36 ft) | N = 10 |
| Broco MK 2 MOD 1 | 12.91 m (43 ft) | N = 10 |
| SC 81 | 3.76 m (12 ft) | N = 20 |
| SC 810 | 7.34 m (24 ft) | N = 10 |
| N1 MK 1 | 15.52 m (51 ft) | N = 3 |
| M-80 | 2.54 (8 ft) | N = 10 |

## B. FRAGMENTATION STUDIES

### 1. In-Air Fragmentation

The amount and size of fragments varied considerably on each device, therefore an average of three firings of each device has been illustrated. There is currently no maximum number or size of fragments allowed for this type device. To put these in perspective, the numbers were compared to the ARD currently on the ANU.

The Broco MOD 0, SC-81, SC-810 and M-80 show significantly lower number of fragments perforating the witness material at all distances. The Broco MOD 1, while producing less fragments at short distances up to 3 feet, produced more fragments than the ARD at the 4 and 5 foot distances. The M-80 produced the predicted two significant fragmentation pieces at all distances. These consisted of the two melted wax end seals. The N1 MK 1 was not tested for air fragmentation. Its actuation method makes it virtually impossible for this device to accidently detonate in the diver support craft.

2. In-Water Fragmentation

The maximum fragmentation travel distance in water for any device was 550 mm (22 inches). As this is much closer than the safe acoustic stand off distance in water, fragmentation is not considered to be a threat to diver safety.

## C. OPERATIONAL RELIABILITY

All of the devices functioned as designed in the configuration tested. Each delay device fired with a 6-7.5 second delay as designed. Two of the devices, however, warrant explanation. First, as stated earlier, the integral fuse on the M-80 went out soon after immersion. The device required modification in order to conduct these tests. Second, the N1 MK 1 requires approximately 30 feet of saltwater to function. Should the device be thrown in shallower water it will fail to operate. This precludes the use of this device in shallow water operations.

All of the devices except the M-80 were heard by the free swimming divers at a distance of 457 m (500 yards) and therefore deemed adequate for normal U.S. Navy SCUBA operations. On numerous occasions, a second M-80 had to be actuated before divers acknowledged the signal.

## D. HUMAN FACTORS

As stated earlier, every device fired as designed in the configured test. On the sole basis of reliability each device scored the same perfect score and, on this aspect, all users approved of each device. However, there was a drastic variance in user opinions concerning how the devices were initiated, ease of use and audible output. A consensus of opinions on each device gathered from questionnaires (Annex A) is provided for each device.

1. Broco MK 2 MOD 0 and MOD 0

These devices are functionally the same. Evaluators preferred the internal fuse for safety reasons. All commented favorably on the ease of operation of these devices. There were no adverse comments on the devices' functional operation.

2. SC-81

Operators did not like the functioning of this device for two reasons. First, the igniting compound on the striker cover was insufficient to reliably light the igniting compound. This often necessitated using a second cover to obtain ignition. Second, the amount of flame produced by the ignition compound, once lit, projected approximately 100 mm (4 inches) from device. All users considered this a personnel hazard and, by most, a fire hazard in small boat operations utilizing portable fuel tanks.

3. SC-810

Most operators like this device for overall functioning. However, they did not like the idea that the striking cap was a separate component from the device.

4. N1 MK 1

Although simple to operate, most operators felt this device was too elaborate. They liked the idea that this device could not inadvertently detonate on the surface but felt that the 30 FSW detonation depth was too deep.

5. M-80

There was several negative comments about this device but most centered around the extensive modifications required to use this device. Most felt that there should be an "all up" device for use.

## E. END ITEM COST

The cost of each of these devices as purchased for this study is listed in Table 2. It should be noted that these costs were for quantities of 100-200 of each device. These prices can be expected to be lower in large quantity buys. Final price determination is beyond the scope of this report.

Table 2

| Device | Cost Each |
|---|---|
| MK 2 MOD 0/1 | $16.00 (Note 1) |
| SC-81 | $2.50 |
| SC-810 | $6.00 |
| N1 MK 1 | $38.00 (Note 2) |
| M-80 | $ 1.05 (Note 3) |

NOTES:

1. Items purchased were prototypes. Discussions with Broco Inc. indicate end item cost will be $10-$12.

2. Cost is approximate and varies based on the monetary exchange rate.

3. Cost is for item as tested, includes M-80 time fuse, and M-60 igniter.

## V. CONCLUSIONS

1. This evaluation was designed to find suitable substitutes for the diver recall devices currently Authorized for Navy Use. As anticipated, all the devices met minimum performance standards. However, based on a comparison of all the factors evaluated, the Broco MK 2 MOD 0 diver recall is the device most suited for use in U.S. Navy diving operations.

2. The Broco MK 2 MOD 1, while similar to the MOD 0, produced significantly more fragmentation and an uncomfortably loud acoustic output.

3. The SC-81 is not suited for U.S. Navy use due to the inability to light the device reliably and the excessive flame produced upon ignition.

4. The SC-810, while adequate in all respects, placed a distant second in the human factors evaluation. It produced a larger, significant fragmentation pattern than

the Broco MK 2. However, should an alternative device be desired, the SC-810 is the device suited second best.

5. The N1 MK 1 is unsuited for Navy use. Its comparatively high cost, inability to function in shallow water operations, and excessive acoustic output make it clearly undesirable.

6. The M-80, currently Authorized for Navy Use, is also deemed unsuitable for Navy use for numerous reasons. It is classified as a class "A" explosive (reference 5) making storage and transportation extremely difficult, it requires excessive modification to function as a recall device, and the acoustic output varies dramatically from device to device. This last factor makes it unreliable as a recall in an emergency situation.

## VI. RECOMMENDATIONS

1. In the interest of diver/support personnel safety, explosive diver recall devices should only be used when operational constraints preclude the use of electronic recall devices.

2. The Broco MK 2 MOD 0 diver recall device should be actively pursued for inclusion on the ANU list. This must include technical and safety review and final product qualification to ensure explosive safety and compatibility.

3. A warning statement "a minimum safe distance for device activation from divers is 11 m" (36 feet) be added to the Broco MK 2s label.

4. As soon as adequate replacement devices are in place for the fleet, the M-80 should be removed from the ANU based on safety and reliability factors.

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## ANNEX A

## RECALL DEVICE QUESTIONNAIRE

DIVE SUPERVISOR NAME: _____

DEVICE TESTED: BROCO MOD 0

BROCO MOD 1

M-80

SC 810

SC 81

N1 MK1

1. WHAT WAS YOUR OVERALL OPINION OF THIS DEVICE?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| POOR | | ADEQUATE | | EXCELLENT |

2. WERE THE DIRECTIONS EASY TO UNDERSTAND?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| CONFUSING | | UNDERSTANDABLE | | EASY |

3. WAS LIGHTING THE DEVICE?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| VERY HARD | | ACCEPTABLE | | VERY EASY |

4. WAS THE LENGTH OF THE DELAY BEFORE DETONATION?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| TOO SHORT | | ADEQUATE | | TOO LONG |

5. DID THE DEVICE FUNCTION AS DESIGNED? YES NO

6. DO YOU HAVE ANY COMMENTS, GOOD OR BAD, ABOUT THE DEVICE?

_____

_____

_____

_____

_____